

Comparison and performance analysis of closed loop controlled nonlinear system connected PWM inverter based on hybrid technique

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Abstract

This paper proposed closed loop control of nonlinear system connected inverter based on the optimal neural controller (ONC). The novelty of the proposed method rests on the hybrid technique which is the combined performance of both, particle swarm optimization (PSO) technique and Radial basis function neural network (RBFNN). It effectively optimizes the feasible solutions by updating the generations, by taking lesser time with greater reliability. In the proposed method, the PSO generates the dataset according to different loading conditions. The RBFNN is trained by using the target control signals along with the corresponding input load voltage error and change in error. Depending on the load variations, the RBFNN predicts the exact control signals of the inverter during the testing time. Since experimentation and comparison of such inverter models on hardware being relatively expensive, the proposed method is implemented in the MATLAB/Simulink platform and the performance has been validated through the comparison analysis with the conventional techniques. The comparison results have proved the superiority of the proposed method. © 2015 The Authors. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Keywords: Optimal neural controller (ONC); Particle swarm optimization (PSO); Radial basis function neural network (RBFNN); Load voltage; Control signals

1. Introduction

An efficient interface between the renewable energy sources (RESs) and the grid with low cost is now basic requirement to meet the demand of end users as there is vast integration of RESs (Yang et al., 2011). The IEEE standard can be maintained by the controlling of RESs and grid interface (Kyritsis et al., 2008; Sun, 2011; Castilla et al., 2009). The power quality mainly depends on inverter output current and the buck/boost facilities which play vital role in feeding a grid with high quality power (Siva Prasad et al., 2008; Sha et al., 2011; Wang and Chang, 2008). Single and three phases are the two categories of grid connected inverter based on the source. Constant power is distinctive advantage of three phase inverter over single phase inverter and therefore it reduces the capacitor value and fewer

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Nomenclature

V_{dc}	DC link voltage
V_{out}	AC output voltage
V_L	load voltage
ΔV_L	error load voltage
V_L^*	reference load voltage
$C\Delta V$	change in error voltage
β	load voltage angle
γ	power angle
θ	power factor angle
f	frequency of the load voltage
R	load resistance
L	load inductance
$P_{inverter}$	output power of the inverter

switches are used for three phase system (Jou et al., 2008; Turner et al., 2010; Chen and Ma Smedley, 2008). Low harmonics and high power factor are the requirements for smooth transmission of power and for that LCL filters are used (Chen and Smedley, 2008; Agorreta et al., 2011; Wang et al., 2010; Shen et al., 2010). LCL gives advantage in cost and dynamics but as low value of inductor is used it results the demerit of resonance, hence there is more complicated control system involves with LCL filter. To mitigate low order harmonics various typical current controller have been used (Kadri et al., 2011; Lee et al., 2012; Shen et al., 2008; Dasgupta et al., 2011a; Castilla et al., 2008). The double loop structure is used to regulate DC-bus voltage and inverter output current as per the reference signal given by the voltage loop (Castelló Moreno et al., 2009). The intention of proportional controller is to inject clear sinusoidal current to the grid even there is presence of nonlinear, unbalanced, grid voltage distortion (Hornik and Zhong, 2011).

From the review of the research work, inverter was working as interface between the grid and RESs and operated in standalone (island) and grid connection mode. The main purpose of this interface was to support the utility at the local load during both modes. Under unbalance loads, nonlinear loads, sudden load disturbances and system uncertainties; it should support the grid with unity power factor and low harmonic current injection as per the IEEE standard. The key to make the inverter more robust to the mentioned conditions was its output current control strategy. The control strategy of the inverter must guarantee its output waveforms to be sinusoidal with fundamental harmonic. For this purpose, close loop current control strategies such as H_∞ repetitive controller, dual closed-loop feedback control, adaptive voltage control and synchronous reference frame proportional integral (SRFPI) controller have been used to meet the power quality requirements imposed by IEEE interconnection standards. The designing of H_∞ repetitive controller is quite complex due to its computations and other techniques also have complexities such as decomposition of output current using reactive power theory and working on synchronous reference frame (SRF) theory. These complexities have made difficulty in designing the closed loop control algorithm of inverter. In literature, some of the technical papers on grid connected inverters; they have not considered its output voltage total harmonics distortion (THD) and most of the algorithms are not tested under nonlinear loads and system uncertainties. This work described the use of hybrid system for the closed loop control of nonlinear system connected inverter.

2. Proposed closed loop control strategy

The structure of the three phase inverter with the proposed control topology is shown in Fig. 1. The three phase inverter consists of three legs (A, B, C), i.e., each leg for each phase and six insulated gate bipolar transistor (IGBT) switches. Each leg consists of two switches; the upper side switches are positive switches and the lower side switches are negative switches. The input of the inverter dc V_{dc} is usually obtained from a DC power supply and it delivers three phase AC output voltage V_{out} to the linear or nonlinear load. The inverter is followed by the LC filter, which is used to eliminate the high frequency pulse width modulation (PWM) signals. The inverter control topology depends on the output performance of the inverter, which is described in Fig. 1.

the proposed ONC technique. Here, the ONC technique is the combined performance of both the PSO technique and RBFNN technique. Initially the PSO technique is used to develop the training dataset of the RBFNN. Depending on the dataset the RBNN can be trained and can predict the optimal control signals of inverter.

3. PSO technique based training dataset generation

The PSO as an optimization device offers a population-based search procedure in which individuals named particles modify their position (state) with time (Sharma et al., 2013). In a PSO system, particles alter their positions by flying around in a multidimensional search space till a comparatively unchanged position has been encountered or till computational limitations are gone beyond (Smita and Vaidya, 2012). Here, the PSO technique is used to optimize the minimum square error (SE) of the load voltage, which is obtained by using the gain parameters k_p , k_i and k_d . From the minimized error, the optimum control signals of the inverter have been predicted. By using the different types of error load voltage and corresponding control signals, the training dataset has been developed. The PSO technique inputs are defined as follows:

$$X_{inp}^p = [X(t)^1, X(t)^2, X(t)^3 \dots X(t)^n] \quad (3)$$

where $X(t) = [\Delta V, C\Delta V]$ is the input error load voltage and change in error load voltage, the gain parameters k_p , k_i and k_d are selected randomly to find the control signal, which should be satisfying the fitness function. The required fitness function is calculated using the following relation (4).

$$Fitness = SE = \frac{1}{2} \sum_{t=1}^n [V_L(t) - V_L^*(t)]^2 \quad (4)$$

where V_L and V_L^* are the actual and reference load voltage. From the fitness function the minimized SE is selected using the following objective functions (5).

$$\Phi = Min \left\{ \sum_{t=1,2,\dots,n} (\Delta V(t))^2 \right\} \quad (5)$$

Then the current particle position is modified, i.e., updating the error load voltage and change in error voltage, which is described in (6).

$$X^{p+1} = X(t)^p + v_{k+1}, \quad k = 1, 2 \dots n \quad (6)$$

Here the particle and the velocity modification are described in (7) and (8).

$$X^{p+1} = [X(t+1)^1, X(t+1)^2, X(t+1)^3 \dots X(t+1)^n] \quad (7)$$

where X^{p+1} is the updated particle; v_{k+1} is the updated velocity.

$$v_{k+1} = w \cdot v_k + c_1 rand^*(P_{best} - X_{inp}^p) + c_2 rand^*(G_{best} - X_{inp}^p) \quad (8)$$

where w is the weight function for velocity of agent k , c_1 and c_2 are the positive constants, $rand^*$ are the random numbers [0,1] and the inertia weight w is defined by the following Eq. (9).

$$w(k) = \frac{w_{\max}(w_{\max} - w_{\min})}{\max . Iter} k \quad (9)$$

where $\max . Iter$ is the maximum number of iteration. Here PSO generates the optimum training dataset, which consists of different types of error voltage, change in error voltage and corresponding control signals.

4. Control signal prediction using RBFNN

The RBFNN works, based on the training and testing algorithm, which overcomes the drawbacks of the artificial neural network (ANN), i.e., ANN not providing better identification performance. Input layer, hidden layer and output layer are the three layers of RBFNN. The network output unit is the total of all weighted unseen units. RBFNN's can be applied in complex modeling due to non linear modeling (Tamboli and Khot, 2013; Cheng Lee et al., 1999). Here,

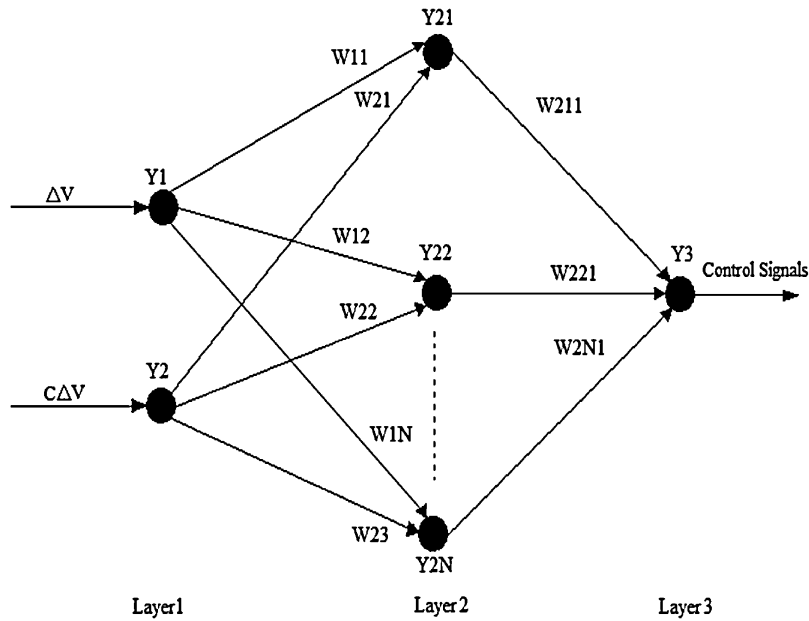


Fig. 3. Structure of RBFNN.

Table 1
Implementation parameters.

Parameters	Value
Battery voltage	100 V
PV voltage	150 V
LL (R)	10 Ω
Internal resistance	1e–3 Ω
Snubber resistance	1e–5 Ω

the RBFNN can predict the control parameters based on the error load voltage and change in error voltage. In the network, neurons are trained with the input for various operating conditions, voltage error and change in error voltage at the specific target control signals. The back propagation algorithm has been utilized for the training process. The structure of the RBFNN network is illustrated in Fig. 3.

Once the training process is completed, the network is trained well to provide the target output i.e. the inverter control signals. In the testing case, the measured error voltage and change in error voltage are applied as an input to determine the control signals. The control signals are converted into the PWM pulses to operate the inverter switches. The proposed ONC structure is described in flow chart in Fig. 4.

5. Results and discussion

Here the three phase inverter tested under different types of loading conditions such as linear load (LL) and non-linear load (NLL) and different types of input sources such as photovoltaic (PV) and battery to validate the performance of the proposed ONC technique. Then the effectiveness of the proposed ONC method is analyzed by comparison analysis with the conventional techniques such as inverter without controller and inverter with closed loop PID controller. The implementation parameters are listed in Table 1.

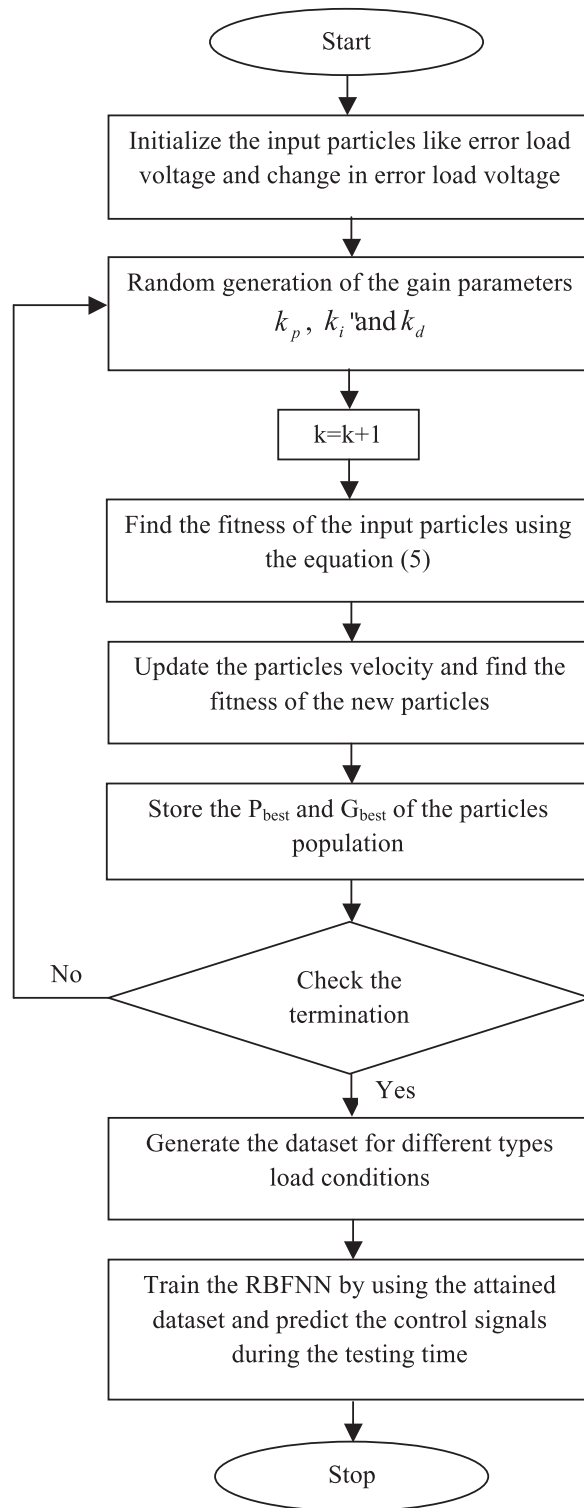


Fig. 4. Block diagram of the proposed hybrid method.

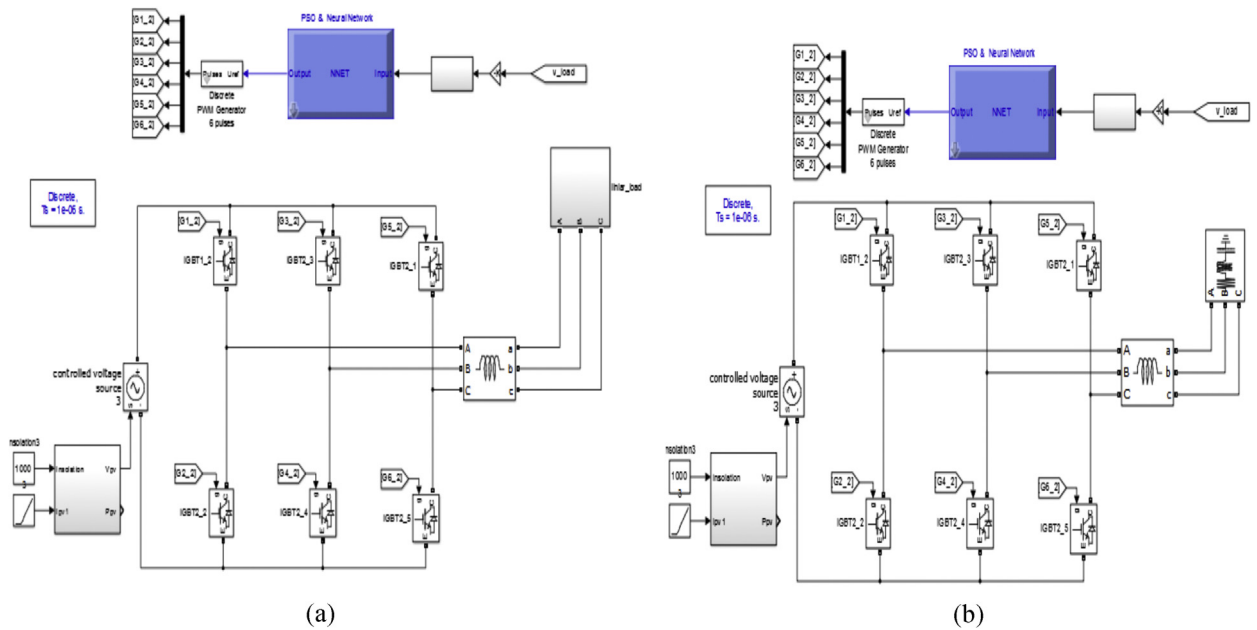


Fig. 5. Three phase inverter using PV source: (a) LL, (b) NLL.

5.1. Three phase inverter with PV source

Fig. 5(a) and (b) shows the three phase inverter with input PV source using proposed ONC technique. It also shows that the output of the inverter is connected with different types of loads such as LL and NLL.

Figs. 6 and 7 described the output power of the inverter with LL and NLL condition using the proposed method and comparison analysis is made with the PID controller and normal inverter without controller. It clearly shows that the proposed method has better power compared to the other techniques.

The three phase inverter using different techniques THD and power factor (PF) is compared in Figs. 8 and 9 respectively.

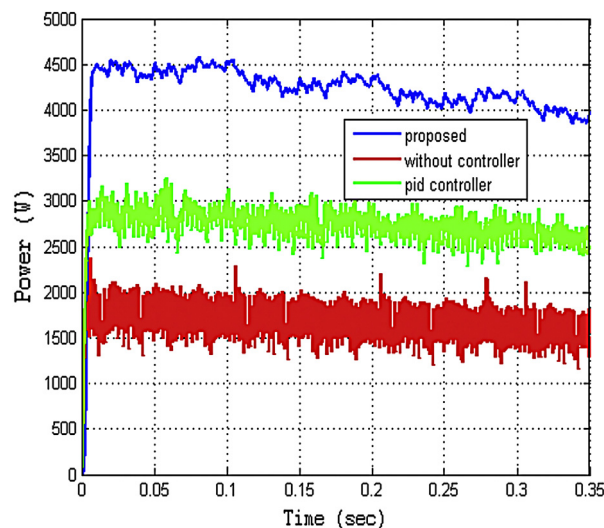


Fig. 6. Output power comparison at LL.

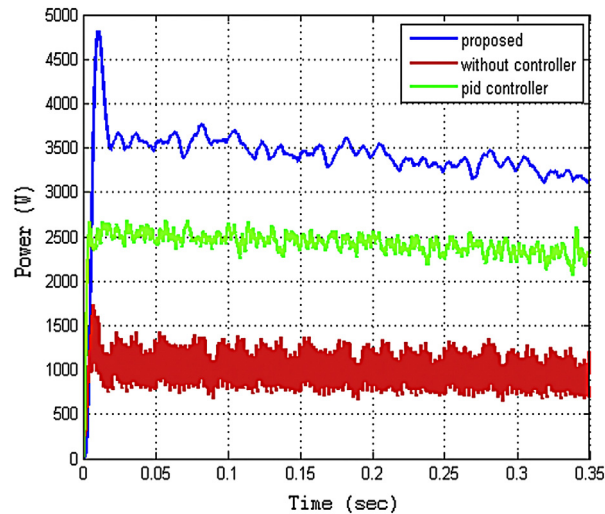


Fig. 7. Output power comparison at NLL.

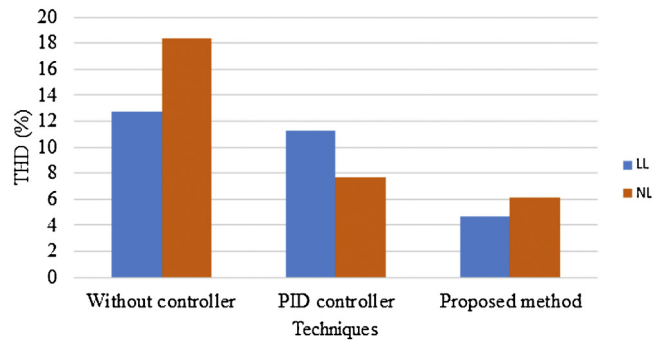


Fig. 8. THD comparison.

The proposed method performance is analyzed by comparing with those of different techniques such as PID controller and normal inverter without controller, which are described in Table 2. Here, the proposed method contains less THD and improved PF value compared to the other techniques. The comparison analysis utilizes different types of system parameters such as THD and PF. From the table, we can understand that the proposed method has reduced THD value to 5.67% and improved PF value to 0.9779 compared to the other techniques.

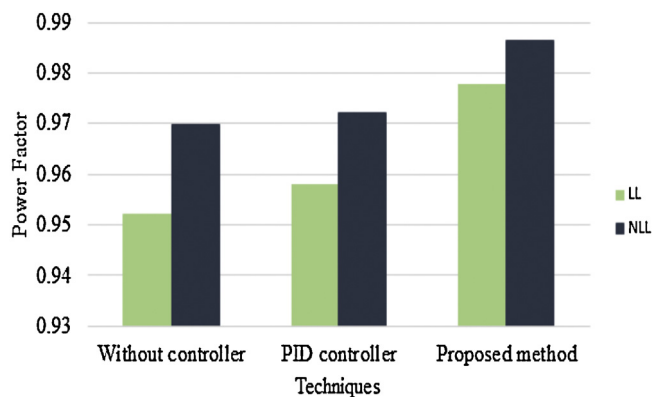


Fig. 9. PF comparison.

Table 2
Three phase inverter performances with PV source using proposed method.

Load	Parameters	Without controller	PID controller	Proposed method
LL	THD	12.70	11.32	4.66
	PF	0.9520	0.9581	0.9779
NLL	THD	18.34	7.69	6.10
	PF	0.9699	0.9721	0.9865

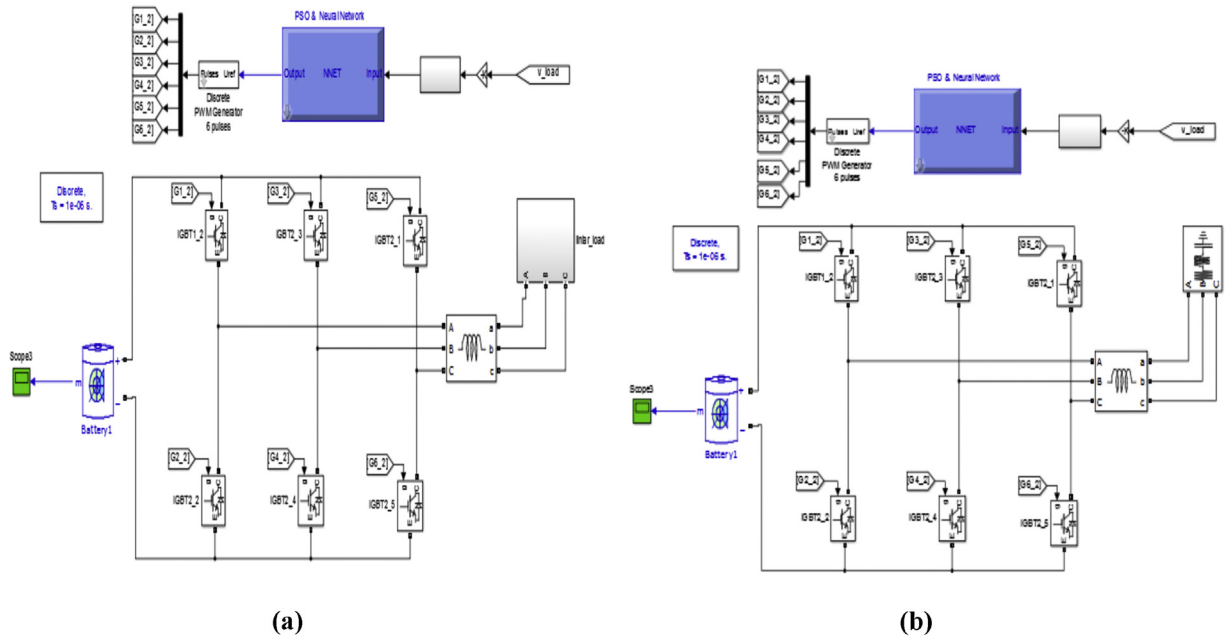


Fig. 10. Three phase inverter using battery source: (a) Linear load, (b) Non-linear load.

5.2. Three phase inverter with battery source

Here the three phase inverter with input battery source using the proposed ONC technique is described. The output of the inverter is connected with different types of loads such as LL and NLL. The structure of the three phase inverter with different types of load is shown in Fig. 10(a) and (b).

Figs. 11 and 12 show the output power of inverter with LL and NLL using proposed method respectively.

The three phase inverter using different techniques such as THD and PF is compared in Figs. 13 and 14 respectively. Here, the proposed method contains less THD and improved PF value compared to the other techniques.

The proposed method performance is analyzed by comparing with different techniques such as PID controller and normal inverter without controller, which is described in Table 3. The evaluation appraisal employs various kinds of system constraints like THD and PF. As evident from the table, we are convinced that our masterpiece technique has ushered in a performance by cutting down THD 5.97% and scaling up PF value to 0.9797 vis-a-vis peer approaches.

Table 3
Three phase inverter performances with battery source using proposed method.

Load	Parameters	Without controller	PID controller	Proposed method
LL	THD	14.96	8.62	4.93
	PF	0.9552	0.9592	0.9780
NLL	THD	16.67	8.16	5.97
	PF	0.9426	0.9696	0.9797

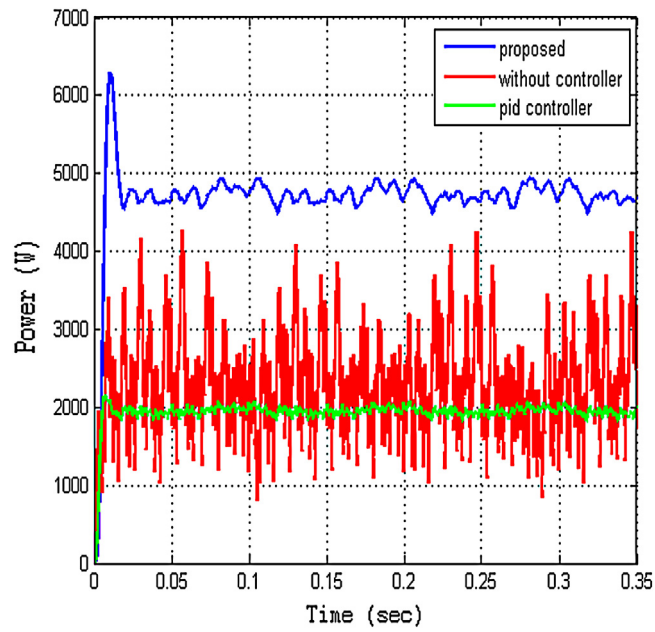


Fig. 11. Output power comparison at LL.

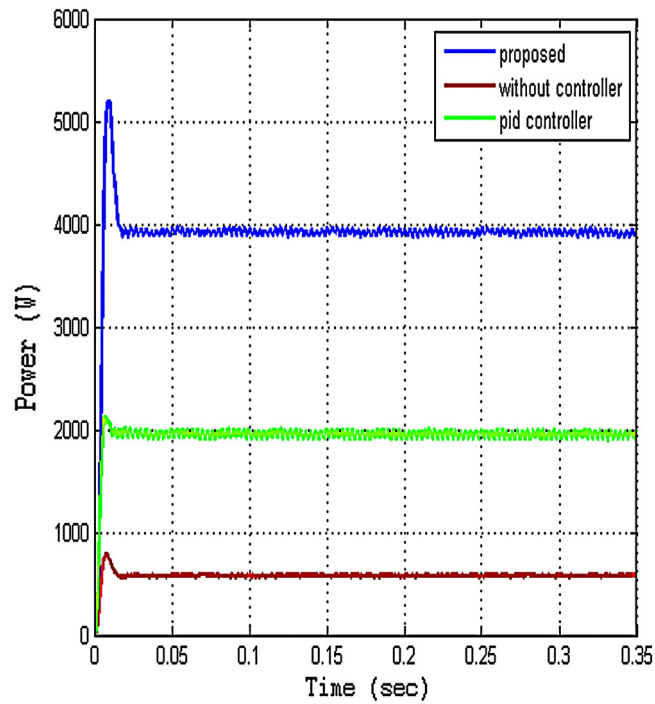


Fig. 12. Output power comparison at NLL.

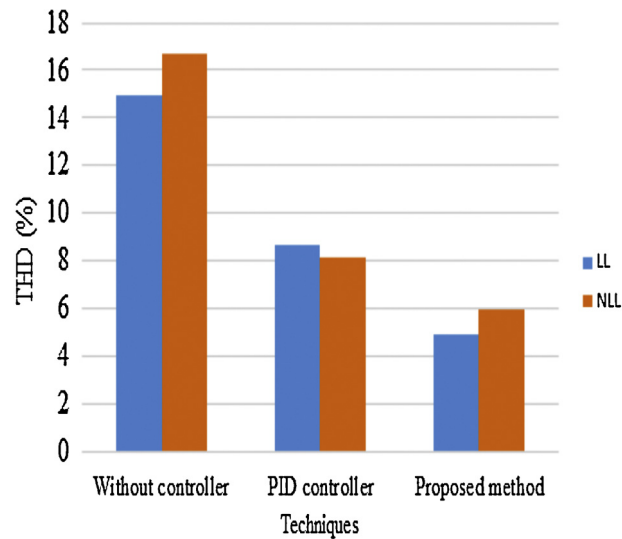


Fig. 13. THD comparison.

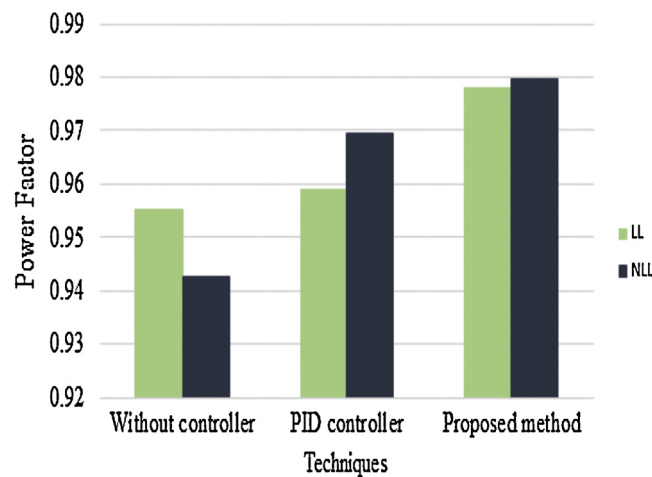


Fig. 14. PF comparison.

6. Conclusion

This paper describes the closed loop control of nonlinear system connected inverter based on the hybrid technique. Here, the PSO technique optimizes the control signals of the inverter for different loading conditions. By using the attained dataset the RBFNN has been trained and it predicts the exact control signals of the inverter at different loading condition. The advantage of the proposed algorithm is that it effectively estimates the efficiency of the inverter during non linear operating conditions, with high accuracy, by considering the level of intrusion. The effectiveness of the proposed method is analyzed by the comparison analysis with the other existing techniques. The comparison results have proved that the proposed method is the most effective technique to reduce the THD, and to improve the efficiency and power

factor of the inverter during the linear and nonlinear load conditions, and it is competent over the other techniques.

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